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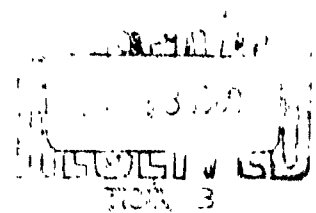
TECHNICAL REPORT 3121

**ATTACHMENT  
OF  
COPPER ROTATING BANDS  
TO  
40 MM PROJECTILES  
BY THE  
ELECTROMAGNETIC-  
PULSE METAL-FORMING PROCESS**

**EUGENE NACHLUPINS**

COPY 43 OF 48

NOVEMBER 1963



**PICATINNY ARSENAL  
DOVER, NEW JERSEY**

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## SECTION I

### INTRODUCTION

The objective of this study was to determine the suitability of the electromagnetic-pulse metal-forming process for the attachment of copper rotating bands to 40mm projectiles.

Originally, the bands were attached to thin-wall steel projectiles by brazing, and to solid aluminum proof projectiles by mechanical swaging. During the production engineering effort for this ammunition, cheaper and faster methods of attachment were sought.

The application of the electromagnetic-pulse metal-forming process appeared to be promising, and a study of this process was made.

## SECTION II

### SUMMARY

A number of tests were performed in order to determine the suitability of the electromagnetic-pulse metal-forming process for the attachment of rotating bands to 40mm projectiles. The tests consisted of attaching rotating bands to simulated and actual projectile bodies, and testing these both statically and by actual firing. The test results were entirely satisfactory.

## SECTION III

### CONCLUSION

The results of the tests indicated that the electromagnetic-pulse metal-forming process is suitable for the attachment of copper rotating bands to 40mm projectiles. It is also concluded, that the process can be advantageously used for ammunition of other calibers, provided some development work is done.

## SECTION IV

### RECOMMENDATIONS

On the basis of the experimental work performed, it is recommended that electromagnetic-pulse metal-forming process be used for the attachment of copper rotating bands to 40mm projectiles.

#### Action Taken

A 40mm proof projectile, with aluminum body, was modified to permit application of this process. Production of the round is now carried out on this basis. The design of the steel projectile bodies was also modified to suit this process. Projectile bodies of this design are now being made and successfully used for testing of fuzes. It is intended to use this modified design for final production.



## SECTION V

### STUDY

In the course of production engineering work for 40mm ammunition, a new process for attaching copper rotating bands to the projectiles was introduced. This is the electromagnetic-pulse metal-forming process, developed by the General Atomic Division, General Dynamics Corporation, San Diego, California. The machine used in this process is sold under the trade name Magneform.

Basically, this process makes use of the electromagnetic field occurring around a conductor through which an electric current is flowing. Another current-carrying conductor, located in this field, will be subjected to a force and will start moving.

As applied to this particular process, a bank of capacitors is discharged through a single-winding coil, whereby a changing electromagnetic field is created. The workpiece -- in our case the rotating band -- represents the second conductor. The current, required to flow in the second conductor, is induced by the changing electromagnetic field around the single-winding coil. The schematic arrangement is as shown in the diagram, Figure 1. The direction of this induced current is such that the conductor will be repelled from the outer coil and moved towards the center.

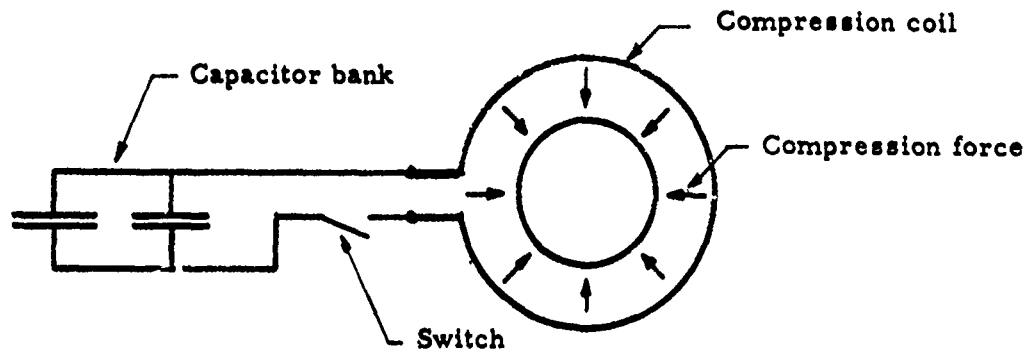


Figure 1. Schematic Arrangement

The voltage applied to the outer coil -- called compression coil -- is very high, and so is the corresponding current through the coil. Very fast-acting electronic switching is used in order to obtain a fast-rising electromagnetic field, thus inducing a high current in the workpiece. All this is necessary to obtain a large repulsive force.

The reactive force on the compression coil is large, and the coil must be of sufficient strength. It is usually made of beryllium copper. Normally the compression coil is furnished with a certain size bore, and inserts called field shapers are used to bring the electromagnetic field close to the workpiece.

The capacitor bank, rectifiers, controls and terminals for the compression coil are assembled in one machine, as shown in Figure 2.



Figure 2. Machine Used in Electromagnetic-Pulse Metal-Forming Process.

Figure 3 shows a section through the operating parts; i.e., compression coil, field shaper and workpiece.

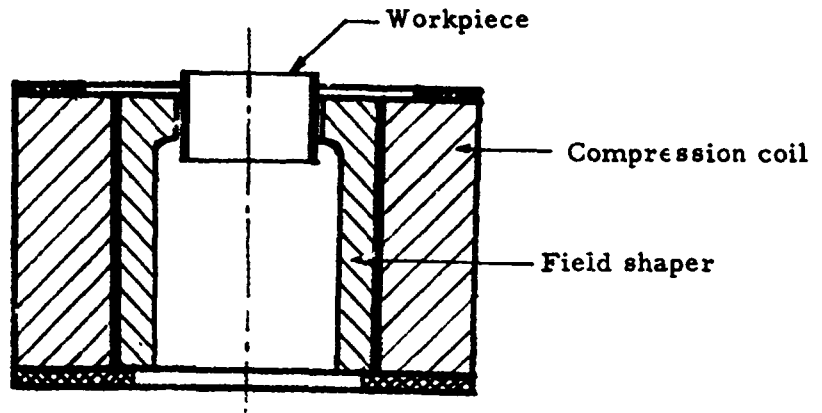


Figure 3. Operating Parts of Electromagnetic-Pulse Metal-Forming Process Machine.

The compression coil does not necessarily have to be located on the machine, but can be installed some distance away, which is desirable when the process is automated and becomes part of a production line. The compression coil can also be water-cooled, which may be necessary with high production rates at high energy levels.

With respect to the attachment of rotating bands to 40mm projectiles, this process offers the following advantages:

- High production rate.
- Simplicity of operation.
- Simplicity of installation.
- Low power requirements.
- Possibility of automating the process.
- Possibility of simplifying the design of the product.
- Low initial and operating cost.

At the present time the process is used for attaching rotating bands to 40mm XM385 Proof Projectiles, and to 40mm thin-wall steel projectile bodies.

In the case of the XM385 Projectile, this process permitted a modification of the design, simplifying and speeding up manufacturing.

The thin-wall steel projectiles were also modified to permit use of the described process instead of brazing the band. Mechanical swaging is undesirable for this application, because the body is easily deformed under forces which are not completely symmetrical all around. The thin rotating band also folds at the gaps between the jaws of swaging tool. With the thin band it would also be very difficult to obtain a good bond without springback, which cannot be tolerated. These drawbacks do not occur with the electromagnetic method, where the force is applied symmetrically, and not only the surface, but each part throughout the thickness is subjected to the force.

The original and modified version of the aluminum projectile is shown in Figure 4 and 5 respectively.

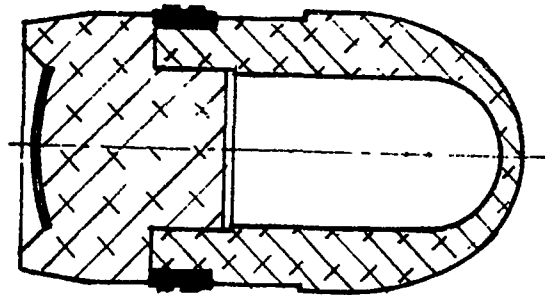


Figure 4. Aluminum Projectile

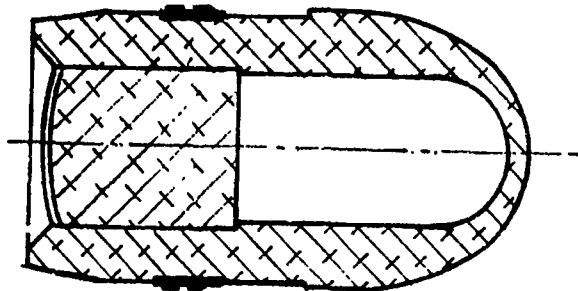


Figure 5. Modified Aluminum Projectile

Originally the rotating band was located between the front and rear part of the projectile, being swaged on a knurled portion of the front part. In the modified version, a much smaller ring is electromagnetically attached to the one-piece body. Fewer machining operations are required and less copper is used. The whole item can be produced cheaper.

In the case of the thin-wall steel projectiles, the rotating bands were brazed to the bodies. In the latest version, the band is attached electromagnetically, thus avoiding the costly brazing operation.

The time required to attach a band to these projectile bodies by the electromagnetic-pulse metal-forming process is only four to five seconds, and considerable savings result from this.

Before applying this process to actual production, a number of tests were performed. The first of these consisted of attaching copper rings 0.10 inch thick to short pieces of steel pipe, simulating projectile bodies. The area on the body where the band was to be attached was provided with a straight knurl. The rings showed distinct marks on the inside, caused by this knurl, but not sufficient to provide a good bond.

At a later date, a number of steel cylinders were prepared with a groove 0.010 inch deep to provide a shoulder for the band. The area in the groove was knurled. These, and band blanks, were assembled by the electromagnetic-pulse metal-forming process at the manufacturer's plant. A number of these completed parts were finish-machined and assembled into projectiles. Others were finish-machined and subjected to various tests. Of these tests, a push test and torque test were considered to be the most important. In order to carry out these tests, a short piece of simulated barrel was made as shown in Figure 6.



Figure 6. Simulated Barrel Used in Tests.

Since these particular tests were performed statically, it was not considered necessary to provide twist in this fixture. The number and dimensions of the lands were, however, the same as in the actual weapon, as well as the lead-in angle into the grooved portion.

The object of the first series of tests was to find if there is any axial slippage when entering the barrel. The tests were performed by pushing the test items into the fixture and through it, in an Instron testing machine, and recording the force. A typical diagram thus obtained is shown in Figure 7.

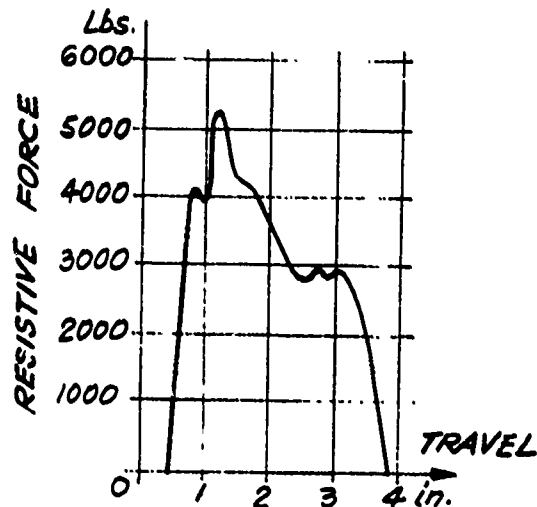


Figure 7. Results of Axial-Slippage Tests.

The maximum force occurred upon entering the rifled portion of the fixture, and varied from 4,000 to 5,000 pounds. After engraving was completed, the force required to keep the test item moving dropped to about 3,000 pounds. The items were examined after they were pushed through, and no slippage whatever was evident. Next, several samples were pushed into the test fixture until engraving was completed. The test fixture was clamped in a dynamometer, and a torque of 2,000 inch-pounds was applied to the test items. Upon removal from the fixture, the items were examined. No peripheral slippage was evident.

After completion of these tests, a number of projectile bodies prepared by this method were assembled into complete projectiles, then assembled into complete rounds and fired from a Mann-barrel launcher against a 2-inch steel-plate target. Examination of the fired projectiles disclosed that no backward slippage of the rotating band had occurred. Some bands showed only a forward movement, varying from 0.1 to 0.3 inch, due to impact on the steel plate. This is not a defect since functioning is in no way affected.

Since these tests were completed, a large number of thin-wall steel projectiles with the rotating bands attached by this process were fabricated and used in testing of fuzes, and no failures of the rotating bands were reported. The firings were conducted at temperatures from 80°F to -65°F.

The situation with the proof projectiles was similar, and all tests were completely successful. Since these projectiles have a thick-wall aluminum body, the groove for the rotating band was made deeper to provide more shoulder area. During the tests, the effect of the electromagnetic-pulse metal-forming process on the hardness of the copper rotating band was investigated. It was found that no appreciable change occurs. The rotating band material is annealed before attachment to the bodies, and the hardness before and after forming is in the area of Rockwell 60F.

The following Figures 8 to 13 illustrate how the projectiles are assembled and their appearance after firing. Figure 14 show the inside of a band removed from a projectile.



Figure 8  
Projectile Without  
Rotating Band



Figure 9  
After Assembly  
of Rotating  
Band



Figure 10  
After Firing

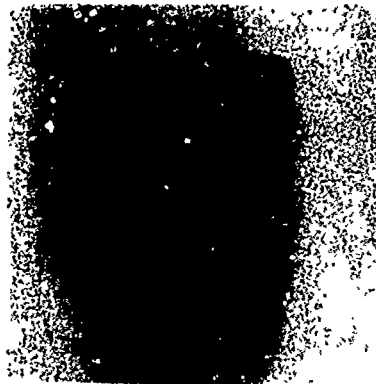


Figure 11  
Projectile Without  
Rotating Band

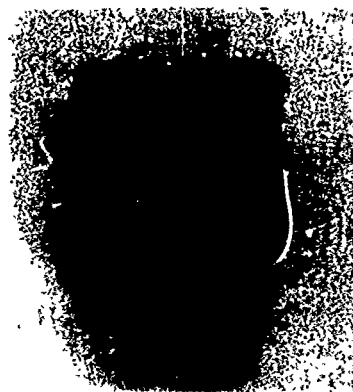


Figure 12  
After Assembly  
of Rotating  
Band



Figure 13  
After Firing

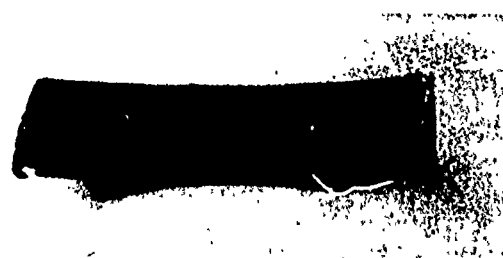


Figure 14  
Inside of Rotating Band  
Removed From Projectile



Figure 8 shows a proof projectile fully machined and ready for anodizing. Figure 9 shows the completed proof projectile, Figure 10 shows the proof projectile recovered after firing into Celotex, Figure 11 shows a steel projectile body ready for banding, Figure 12 shows the projectile banded and finish-machined, Figure 13 shows a steel projectile recovered from firing into Celotex, Figure 14 shows the inner face of a rotating band which was attached to a projectile by the electromagnetic-pulse metal-forming process. The deep impressions show how well the band was bonded to the knurled area on the projectile.

Figure 15 shows a test projectile body recovered from firing onto a 2-inch steel plate. The aluminum nose disintegrated. The slight forward slippage of the rotating band occurred due to inertia force upon impact. Evidently this is of no consequence with respect to functioning.

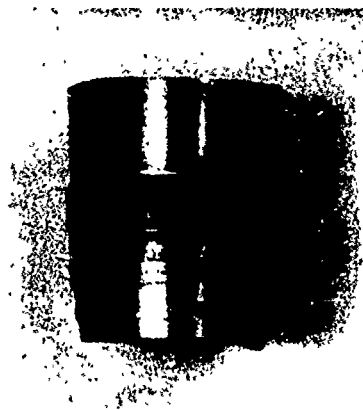


Figure 15. Projectile Body After Firing Onto 2-Inch Steel Plate.

When attaching rotating bands by the described process, several points should be kept in mind. In the case of steel projectiles, the bodies should be placed on a solid steel mandrel to back the wall up in order to prevent too much deformation. In the case of the thick-wall aluminum proof projectiles, this is not necessary. Further, the energy applied to the band during the forming process should be adjusted to obtain proper bond, evidenced by good impression of the knurl on the inside of the band. If the energy applied exceeds this optimum energy level by too much, the band may bounce back by a short distance and the bond may be unsatisfactory. Once the proper energy level is found, it can be repeated indefinitely since any setting of the

control corresponds to a definite energy level which practically can be considered to be invariable. If the bond is unsatisfactory, a slippage during machining can occur. A slippage in the barrel during firing is not likely to occur, since in this case the band is constrained and cannot ride up on the knurl. At the time the band enters the rifling, the  $5^{\circ}$  lead angle will cause a radial component forcing the band onto the seat.

In order to check this, the torque tests previously described were repeated with finished steel bodies and thick-walled aluminum bodies. Tests with aluminum projectiles showed that at a torque of 4,600 inch-pounds the copper started to shear in the engraving, but no slippage of the band occurred. At 7,000 inch-pounds shearing continued, and again no slippage of the band occurred. The body itself began to deform in the jaws of the dynamometer holding device. With steel bodies the torque could be brought up to 3,200 inch-pounds, at which point the body was severely deformed, but no slippage of the band occurred.

From these tests and the results obtained from actual firings, it was concluded that the rotating bands will be damaged before slippage of the band will occur.

The torque which occurs during firing was calculated to be 1,670 inch-pounds, which is well below the values required to cause damage to the rotating bands.

The present arrangement for attaching the bands by the described process is shown in Figure 16.

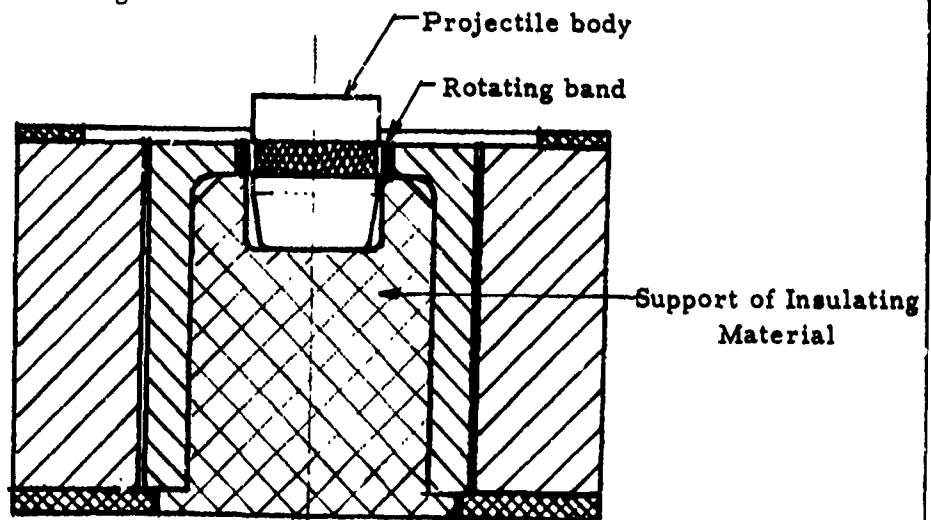


Figure 16. Arrangement for Attaching Rotating Bands.

On the basis of the favorable results obtained, it is intended to use this method for mass production of 40mm ammunition.

There is no doubt that this process can be used advantageously for other types of ammunition and many other purposes.

**ABSTRACT DATA**

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Picatinny Arsenal, Dover, New Jersey

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3. Attachment Process

I. Nachlupins, Eugene

**UNITERMS**

Attachment Process  
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Magneform  
Process  
40mm  
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40 mm  
Nachlupins, Eugene

It was concluded that the process can also be developed for use on ammunition of other calibers.

An aluminum 40 mm proof projectile was modified to permit use of this process, and modified rounds are now being produced. Modified steel projectile bodies are also being made and successfully used for testing of fuzes. The modified design is intended for final production.

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